IX. BADLANDS NATIONAL PARK

A. GENERAL DESCRIPTION

Badlands National Monument was authorized in 1929 in recognition of the remarkable geomorphology and abundant fossils in this region of South Dakota. In addition, a memorandum of agreement between the Oglala Sioux and the Secretary of the Interior added 58,000 ha of reservation land to the monument. The entire 100,000-ha protected area was officially designated as Badlands National Park (BADL) in 1978. Visitation (over 1.5 million in 1991) has increased substantially since that time (BADL 1994). For administrative purposes, the park contains units referred to as the North Unit (which contains Badlands Wilderness) and South Unit (on the Pine Ridge Reservation, including Palmer Creek). The southern portion of the park is managed by the National Park Service in consultation with the Oglala Sioux Tribe and within the context of a reservation, where some agreed upon consumptive uses are permitted.

The most prominent feature of BADL is the dramatic scenery that can be observed throughout the park. Erosional landscapes and a variety of geological substrates of different ages present a visual diversity of colors and patterns, and trace a fascinating geomorphological history in this region. The Badlands Wilderness, surrounded by cliffs and pinnacles, provides vistas of colorful buttes amidst grassland ecosystems. Bison (*Bison bison*) and other native ungulates can be seen throughout the park.

1. Geology

The badlands areas of southwestern South Dakota occur where the widespread peneplain is actively dissected by continual erosion. Erodible geological substrates and an arid climate which discourages rapid vegetation growth lead to a dynamic landscape with active erosion, gullying, and landslides. Geological materials of the White River Group consist of very fine clays which are poorly consolidated, with interspersed beds of sandstone and isolated concretions (Martin 1987, Froiland and Weedon 1990). In addition to clays, the layered badlands contain several different geological materials, including volcanic ash, chalcedony, quartz, and calcite. The distinctive geomorphological features of BADL are not only visually beautiful but contain one of the richest fossil-containing Tertiary deposits in North America.

2. Climate

BADL has hot summers and cold, dry winters. Temperatures reach as high as 40 ºC and as low as -40 ºC. Precipitation is highly variable but averages 40 cm per year, most of this falling as rain during spring and summer; average total snowfall depth is 60 cm. Rain often falls in intensive storms, producing torrents and ephemeral streams that provide the energy for further erosion of the badlands.

The predominant direction of air mass movement is from west to east over South Dakota. Wind rose data from BADL during the period 1989 through 1995 show that winds from the northwest predominate between November and April (Weber 1982). A second frequent wind direction, which tends to occur between May and October, is from the east.

3. Biota

BADL contains ecosystems that are still in the process of recovery from human use during settlement times and during the time park lands were privately owned. Much of this area was previously used for dryland farming, grazing by domestic livestock, market hunting of wildlife, and fossil collecting. A 1919 survey of the Badlands area revealed that there were few native wildlife or trees, although they were abundant just a few decades earlier. Starting in the 1930s, grasslands began to slowly recover with the inception of active resource management and the cessation of livestock grazing. About 97% of the park is now managed for natural zones, and various restoration efforts are underway to encourage the development of sustainable populations of native plants and animals. Inventory of park resources is incomplete and there is little ongoing monitoring. There is little or no information on bird, fish, reptile, amphibian, cave life, or aquatic systems. Knowledge of plant communities, species composition, or carrying capacities for the wildlife they support is likewise lacking. Efforts are underway, however, to improve inventory and monitoring of the condition of natural resources in the park (Plumb undated).

The dominant vegetation of BADL is often referred to as mixed-grass prairie, although this designation encompasses a variety of grassland communities (Cushman and Jones 1988, Froiland and Weedon 1990). The dominant grassland community of this region occurs as a moderately dense short to medium tallgrass prairie dominated by western wheatgrass (*Agropyron smithii*), green needlegrass (*Stipa viridula*), blue grama (*Bouteloua gracilis*), and needle-and-thread (*Stipa comata*). Associated species include fringed sage (*Artemisia frigida*), prairie junegrass (*Koeleria pyramidata*), little bluestem (*Andropogon scoparius*), silky wormwood (*Artemisia dracunculus*), purple coneflower (*Echinacea angustifolia*), and various other forbs. Blue grama and buffalo grass (*Buchloe dactyloides*) form a mosaic of patches in combination with western wheatgrass and green needlegrass. The mixed-grass prairie of BADL, although still recovering, has been recognized as the finest extant. That portion of the prairie preserved in the Badlands Wilderness is especially important for its thriving population of black-tailed prairie dogs (*Cynomys ludovicianus*) (BADL 1994).

Trees are relatively uncommon on a large scale but are locally common in areas of higher soil moisture such as drainages with ephemeral streams and ponds, or slumps near the shoulder slope of rocky ridges, which produce topographic depressions. Red cedar (*Juniperus virginiana*) and Rocky Mountain juniper (*J. scopulorum*) dominate the vegetation in these rocky slumps. In lower, flatter areas of the landscape, several deciduous species dominate, including plains cottonwood (*Populus deltoides*), peach-leaved willow (*Salix amygdaloides*) and other willows, box elder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), and American elm (*Ulmus americana*). Riparian woodland in this region is best developed along the White River. Much of BADL at lower elevations and along eroded backslopes is sparsely vegetated and, in the case of highly active erosional situations, devoid of vegetation. Species that are commonly found in these areas include curly-cup gumweed (*Grindelia squarrosa*), broom snakeweed (*Gutierrezia sarothrae*), wild buckwheat (*Polygonum convolvulus*), and a wide range of rare plant species.

Animal populations of the BADL region are probably still recovering from hunting and habitat alteration. The bison is perhaps the species most valued by park visitors, and considerable effort has been expended to restore populations of these native ungulates. In 1964, bighorn sheep (*Ovis canadensis canadensis*) were introduced into the park to replace the extinct Audubon bighorn sheep (*O. canadensis auduboni*) which were present until the 1920s. The herd is currently divided into three bands, two in the North Unit and one in the South Unit, for a total of about 110 animals. As in most other areas of the western United States, predators such as the grizzly bear (*Ursus arctos* subsp. *horribilis*) and gray wolf (*Canis lupus*) have been extirpated, with little likelihood of reintroduction in the forseeable future.

Other common mammals in the park include mule deer (*Odocoileus hemionus*), whitetail deer (*O. virginianus*), American pronghorn (*Antilocapra americana*), coyote (*Canis latrans*), black-tailed prairie dog, white-tailed jackrabbit (*Lepus townsendii*), cottontail (*Sylvilagus floridanus*), and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*). In addition, the park has an active program for restoring black-footed ferret (*Mustela nigripes*) populations. Common or highly valued bird species include golden eagle (*Aquila chrysaetos*), three hawk species (*Buteo* spp.), magpies (*Pica pica*), western meadowlark (*Sturnella neglecta*), cliff swallow (*Hirundo pyrrhonata*), turkey vulture (*Cathartes aura*), great-horned owl (*Bubo virginianus*), burrowing owl (*Athene cunicularia*), and killdeer (*Charadrius vociferus*).

Other important animals include prairie rattlesnake (*Crotalus viridis*), bullsnake (*Pituophis melanoleucus sayi*), western painted turtle (*Chrysemys picta belli*), and blotched tiger salamander (*Ambystoma tigrinum melanostictum*). A conspicuous scarcity of lizards has been noted at BADL with the only lizard found in the park being the rare eastern short-horned lizard (*Phrynosoma douglassi brevirostre*). Several species of reptiles considered rare by the state of South Dakota which would be expected to be found within the park include the six-lined racer (*Cnemidophorus sexlineatus*), lesser earless lizard (*Holbrookia maculata maculata*), many-lined skink (*Eumeces multivirgatus multivirgatus*), and western box turtle (*Terrapene ornata*).

4. Aquatic Resources

The White River is the major stream in the BADL region. Although the river actually cuts through only a small portion of the park (near the White River Visitor Center), many tributaries from the park enter the White River. It is responsible for many of the large-scale patterns of erosion found in the area. Sage Creek is an ephemeral tributary of the Cheyenne River in the western part of the North Unit. Bear Creek, Battle Creek, and Cedar Creek all have their headwaters in BADL and are tributaries of the Cheyenne River. A small portion of the park has intermittent upper tributaries that drain in the Bad River. The White, Cheyenne and Bad Rivers are all part of the Missouri River system. There are many small ephemeral streams and small ponds in drainages and convexities throughout the park. Both standing and running waters in the park nearly always have a high sediment content, and most standing water is cloudy in appearance because it contains fine clays in colloidal suspension. Water is clearly a limiting factor to vegetation and animals in this region. There are also a number of stock dams and wildlife water impoundments that provide a year-round source of water for domestic livestock in the South Unit and a variety of wildlife throughout the park.

B. EMISSIONS

Emissions of criteria pollutants in the immediate vicinity of BADL are relatively low. Ranching and farming are the primary industries on the Pine Ridge Reservation, and the area is sparsely populated with no major metropolitan areas (Weber 1982). South Dakota has lower emissions of SO_2, VOCs and NO_x than other Rocky Mountain and northern Great Plains states. Pollutant sources close to BADL include Rapid City and Black Hills Power & Light Company, 80 and 120 km to the northwest of BADL, respectively. Rapid City is the only urban area in South Dakota that does not meet EPA standards for particulates. Other large sources, including coal-fired power plants, are located in the easternmost portion of the state, remote and generally downwind from BADL. A summary of state-wide emissions of NO_x, SO_2 and VOC for 1994 is listed in Tables II-2, II-3, and
II-4.

While small quantities of emissions from Rapid City sources may reach BADL, of greater importance are regional-scale sources located to the west of BADL. Emissions of NO_x and SO_2 from industrial and electric-utility facilities in eastern Wyoming and western South Dakota are the greatest potential concern at BADL. Annual emissions of NO_x in Wyoming are particularly high, and a portion of these emissions may reach the BADL airshed. Westerly winds transport NO_x, SO_2, and VOCs eastward over the Black Hills region and BADL, providing sufficient precursors for ozone formation during the summer when it is sunny and warm. The development of additional coal-fired power plants in eastern Montana and eastern Wyoming would increase emissions transported to BADL.

C. MONITORING AND RESEARCH ACTIVITIES

1. Air Quality

Table II-5 is a summary of current air quality monitoring being conducted in BADL.

a. <u>Wet Deposition</u>

The NADP/NTN site at Cottonwood (approximately 20 km northeast of BADL) is used to represent wet deposition at BADL. Wetfall chemistry data are available for this location since 1983. The data indicate no particular trends during this period of time (Table IX-1). Hydrogen ion (acidic) inputs are relatively low, which suggests that the acidity of wet deposition is not a concern in this area. Ionic deposition of N and S are considerably higher than that of other elements. Sulfate deposition is moderately high due to geological sources of this ion. Despite these ionic concentrations of sulfate, wet deposition of S averages only 1.1 kg/ha/yr, which is quite low (Table IX-2). Average total inorganic nitrogen deposition is only 2.1 kg/ha/yr, with approximately equal contributions from nitrate and ammonium. The values for S and N deposition, in combination with wetfall input of hydrogen and other ions, indicate that BADL is a relatively clean site and that there is no apparent threat from acidic deposition at the present time.

b. Occult/Dry Deposition

There are no dry deposition data available in the vicinity of BADL. Dry deposition is not expected to have a major impact on natural resources in the park.

Table IX-1. Wetfall chemistry at the NADP/NTN site near BADL. Units are in μeq/L, except precipitation (cm).

Year	Precip	H^+	SO_4^{2-}	NH_4^+	NO_3	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-
1995	47.6	5.6	12.2	16.8	15.9	8.2	1.4	2.1	0.5	1.7
1994	38.2	6.3	16.9	23.6	18.7	11.1	2.0	2.1	0.7	2.0
1993	58.9	3.0	16.1	22.1	16.5	8.8	1.8	2.6	0.8	2.0
1992	53.3	6.3	18.2	20.6	15.1	6.6	1.1	1.7	0.5	1.6
1991	62.7	2.7	13.7	19.1	14.5	11.1	1.8	2.1	0.6	2.7
1990	29.1	4.4	16.0	22.5	18.8	8.7	1.8	2.8	0.5	3.0
1989	29.4	3.7	16.3	18.7	16.8	10.4	2.0	2.7	0.6	2.5
1988	36.1	4.6	12.9	5.5	11.1	8.6	1.4	2.5	0.5	1.4
1987	31.7	4.6	17.6	23.6	17.7	7.4	1.8	2.7	0.7	2.2
1986	56.4	5.9	17.9	12.6	15.7	12.5	2.2	2.3	0.9	1.9
1985	26.3	3.5	18.4	17.5	17.2	14.2	3.5	2.6	1.4	3.2
1984	41.7	1.9	20.5	22.6	17.7	14.4	4.2	3.7	1.0	3.0
Average	42.6	4.4	16.4	18.8	16.3	10.2	2.1	2.5	0.7	2.3

Table IX-2. Wet deposition (kg/ha/yr) of sulfur and nitrogen at the NADP/NTN site near BADL.

Date	Sulfur	NO_3-N	NH_4-N	Total Inorganic N
1995	0.9	1.1	1.1	2.2
1994	1.0	1.0	1.3	2.3
1993	1.5	1.4	1.8	3.2
1992	1.6	1.1	1.5	2.7
1991	1.4	1.3	1.7	3.0
1990	0.8	0.8	0.9	1.7
1989	0.8	0.7	0.8	1.5
1988	0.8	0.6	0.3	0.8
1987	0.9	0.8	1.1	1.8
1986	1.6	1.2	1.0	2.2
1985	0.8	0.6	0.6	1.3
1984	1.4	1.0	1.3	2.4
Average	1.1	1.0	1.1	2.1

c. Gaseous Monitoring

BADL joined the air quality monitoring network in 1987 with the installation of a continuous ozone analyzer. Continuous ozone monitoring has since been discontinued and there is no monitoring of gaseous pollutants currently being conducted at the park (Table II-5). Passive ozone monitoring was initiated at one location in 1997.

Ozone was monitored at BADL from 1988 to 1992. Table IX-3 is a summary of ozone concentrations at BADL. As Table IX-3 indicates, the highest 1-hour ozone concentration measured at the park was 72 ppbv (1988). Ozone concentrations are similar to those found at GLAC, THRO, and YELL and significantly lower than those at ROMO. During the ozone monitoring period, BADL had some of the lowest average ozone concentrations in the NPS monitoring network and was one of only 10 NPS sites that maintained second-highest 1-hour ozone averages at or below 75 ppbv during 1987-1991 (Joseph and Flores 1993). Perhaps more importantly, with respect to damage to sensitive plant species, the mean daytime 7-hour ozone concentration during the growing season ranged between 38 and 45 ppbv during this time period. These levels are below those found to damage sensitive plant species. The SUM60 exposure index is another indicator that can be important in assessing ozone exposures of plant species. This index is the sum of all hourly ozone concentrations equaling or exceeding 60 ppbv. The SUM60 index at BADL ranged between 793 and 5,251. For comparison, National Parks in highly polluted areas (e.g., southern California) can have SUM60 exposure indexes exceeding 100,000 ppbv-hour (Joseph and Flores 1993).

Table IX-3. Summary of BADL ozone concentrations (ppbv) from NPS monitoring sites (Joseph and Flores 1993).

	1988	1989	1990	1991
1-hour maximum	72	71	63	66
Average daily mean	34	31	29	31
Growing season 7-hour mean	45	43	38	40
SUM60 exposure index (ppbv-hour)	5,251	3,079	793	738

The state of South Dakota also does not currently monitor gaseous pollutants. Between 1975 and 1986, gaseous monitoring was conducted by the South Dakota Department of Environment and Natural Resources using SO_2/NO_2 bubblers sampling every sixth day (since levels did not warrant continuous daily operation) at various locations around the state. Measured levels of SO_2 rarely exceeded the threshold limit of the instruments (1 ppbv). The data are on file with the South Dakota Air Monitoring Program.

The low SO_2 values at BADL measured by NPS-ARD (four months per year, Table IX-4) are in agreement with the values measured by the state and with the values measured at other national parks in the region indicating that SO_2 is not an issue of immediate concern in BADL.

Table IX-4. Maximum and mean SO_2 24-hour integrated sample for BADL. The clean air baseline is estimated to be 0.19 ppbv (Urone 1976). (Source: J. Ray, NPS Air Resources Division)

SO_2 concentration (ppbv)	1988	1989	1990	1991	1992	1993
Maximum	3.64	2.04	1.02	0.62	0.60	2.35
Mean	0.10	0.14	0.16	0.13	0.11	0.38

2. Water Quality

Surface waters are expected to be well-buffered against acid inputs. EPA's STORET data base contains 1,971 pH measurements for southwestern South Dakota, in an area that includes BADL. Only one measurement showed pH less than 6.1, having a reported pH of 1.5, and it was either due to an error or to direct acid discharge (e.g., acid mine drainage). The first pH percentile was 6.6. In other words, 99% of the measured values were higher than pH 6.6. Similarly, 99% of the calcium measurements (n=236) were higher than 10 mg/L (500 μeq/L). Surface water sulfate concentrations tended to be very high due to geological sources of SO_4^{2-}. The median SO_4^{2-} concentration (n=77) in the data set was 88 mg/L (1,800 μeq/L). Thus, none of the available water-quality data suggest acid-sensitivity. There is no evidence to suggest that surface waters in BADL would be responsive to acidic deposition impacts. Acidic deposition, especially the low levels currently experienced at BADL, should not be a threat to water quality due to the high base cation content and pH of the water and soils of the region.

3. Terrestrial

No studies have been performed on the effects of air pollutants on the terrestrial resources of BADL. Park management acknowledges that baseline pollutant monitoring has been carried out to some degree and that the next step is to identify air pollution sensitive species, document their current status, and establish a monitoring plan.

4. Visibility

As part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network, visual air quality in BADL has been monitored using an aerosol sampler, transmissometer, and camera. The aerosol sampler has operated from March 1988 through the present and is located at park headquarters slightly south of the Cedar Pass Visitor Center. The transmissometer has operated from January 1988 through the present and is located at the park's northeast entrance. The 35mm camera operated from August 1987 through March 1995. The camera system was located at the Pinnacles Overlook, approximately 14 miles south of Wall, South Dakota, and viewed Sheep Mountain to the southwest. Data from this IMPROVE site have been summarized to characterize the full range of visibility conditions for the March 1988 through February 1995 period, based on seasonal periods (Spring: March, April, and May; Summer: June, July, and August; Autumn: September, October, and November; and Winter: December, January, and February) and annual periods (March through February of the following year, e.g., the annual period of 1994 includes March 1994 through February 1995). Complete descriptions of visibility characterization, mechanisms of sources and visibility impacts, and IMPROVE monitoring techniques and rationale are provided in the Introduction of this document.

a. Aerosol Sampler Data - Particle Monitoring

IMPROVE aerosol samplers consist of four separate particle sampling modules that collect 24-hour filter samples of the particles suspended in the air. The filters are then analyzed in the laboratory to determine the mass concentration and chemical composition of the sampled particles. Particle data can be used to provide a basis for inferring the probable sources of visibility impairment. Practical considerations limit the data collection to two 24-hour samples per week. (Wednesday and Saturday from midnight to midnight). Detailed descriptions of the aerosol sampler, laboratory analysis, and data reduction procedures used can be found in the draft Standard Operating Procedures and Technical Instructions for the IMPROVE Aerosol Sampling Network (U.C. Davis, 1996).

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient in Mm^{-1} (inverse megameters) from experimentally determined extinction efficiencies of important aerosol species. The extinction coefficient represents the ability of the atmosphere to scatter and absorb light. Higher extinction coefficients signify lower visibility. A tabular and graphic summary of average reconstructed extinction values by season and year for the March 1988 through February 1995 period are provided in Table IX-5 and Figure IX-1, respectively.

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at BADL to specific aerosol species (Figure IX-2). The species shown are Rayleigh, sulfate, nitrate, organics, elemental (light absorbing) carbon, and coarse mass. The sum of these species account for the majority of non-weather related extinctions. Extinction budgets are listed by season and by mean of cleanest 20% of days, mean of the median 20% of days, and mean of the dirtiest 20% of days. The "cleanest" and "dirtiest" signify lowest fine mass concentrations and highest fine mass concentrations respectively, with "median" representing the 20% of days with fine mass concentrations in the middle of the distribution. Each budget includes the corresponding extinction coefficient, visual range (in kilometers), and deciview (dv). Standard Visual Range (SVR) can be expressed as:

$$SVR = 3912 / (b_{ext} - b_{Ray} + 10)$$

Table IX-5. Seasonal and annual average reconstructed extinction (Mm^{-1}) for BADL, March 1988 through February 1995.

Year	Spring (Mar, Apr, May)		Summer (Jun, Jul, Aug)		Autumn (Sep, Oct, Nov)		Winter (Dec, Jan, Feb)		Annual (Mar - Feb)[a]	
	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)
1988	47.7	82	55.6	70	36.7	107	38.5	102	45.4	86
1989	53.8	73	51.5	76	39.5	99	42.0	93	46.4	84
1990	50.9	77	48.3	81	40.1	98	38.5	102	44.1	89
1991	50.5	77	52.2	75	39.5	99	42.2	93	46.1	85
1992	55.2	71	46.7	84	43.7	90	59.0	66	51.0	77
1993	49.1	80	37.1	105	36.7	107	51.5	76	43.2	91
1994	45.4	86	48.6	80	44.1	89	45.6	86	45.8	85
Mean[b]	50.4	78	48.6	80	40.0	98	45.3	86	46.1[c]	85[3]

[a] Annual period data represent the mean of all data for each March through February annual period.
[b] Combined season data represent the mean of all seasonal means for each season of the March 1988 through February 1995 period.
[c] Combined annual period data represent the mean of all combined season means.

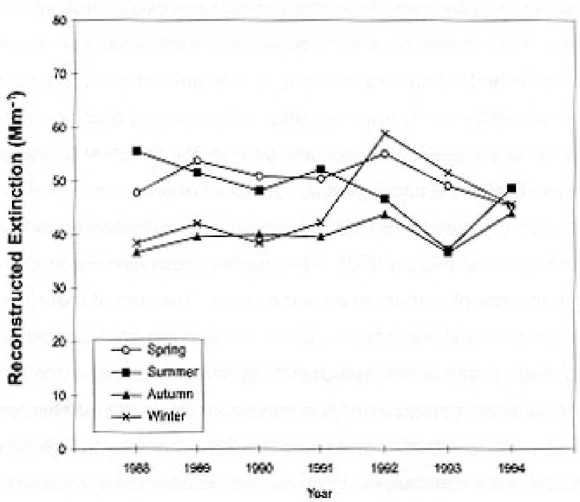


Figure IX-1. Seasonal average reconstructed extinction (Mm^{-1}) for BADL, March 1988 through February 1995.

Figure IX-1. Seasonal average reconstructed extinction (Mm^{-1}) for BADL, March 1988 through February 1995.

where b_{ext} is the extinction coefficient expressed in inverse megameters (Mm^{-1}), b_{Ray} is the site specific Rayleigh values (elevation dependent), 10 is the Rayleigh coefficient used to normalize visual range, and 3912 is the constant derived from assuming a 2% contrast detection threshold. The theoretical maximum SVR is 391 km. Note that b_{ext} and SVR are inversely related: for example, as the air becomes cleaner, b_{ext} values decrease and SVR values increase.

Deciview is defined as:

$$dv = 10 \ln(b_{ext} / 10\ Mm^{-1})$$

where b_{ext} is the extinction coefficient expressed in inverse megameters (Mm^{-1}). A one dv change is approximately a 10% change in b_{ext}, which is a small but perceptible scenic change under many circumstances. The deciview scale is near zero (0) for a pristine atmosphere and increases as visibility is degraded. The segment at the bottom of each stacked bar represents Rayleigh scattering, which is assumed to be a constant 10 Mm^{-1} at all sites during all seasons. Rayleigh scattering is the natural scattering of light by atmospheric gases. Higher fractions of extinction due to Rayleigh scattering indicate cleaner conditions.

The reconstructed extinction data are used as background conditions to run plume and regional haze models. These data are also used in the analysis of visibility trends and conditions. The measured extinction data are used to verify the calculated reconstructed extinction and can also be

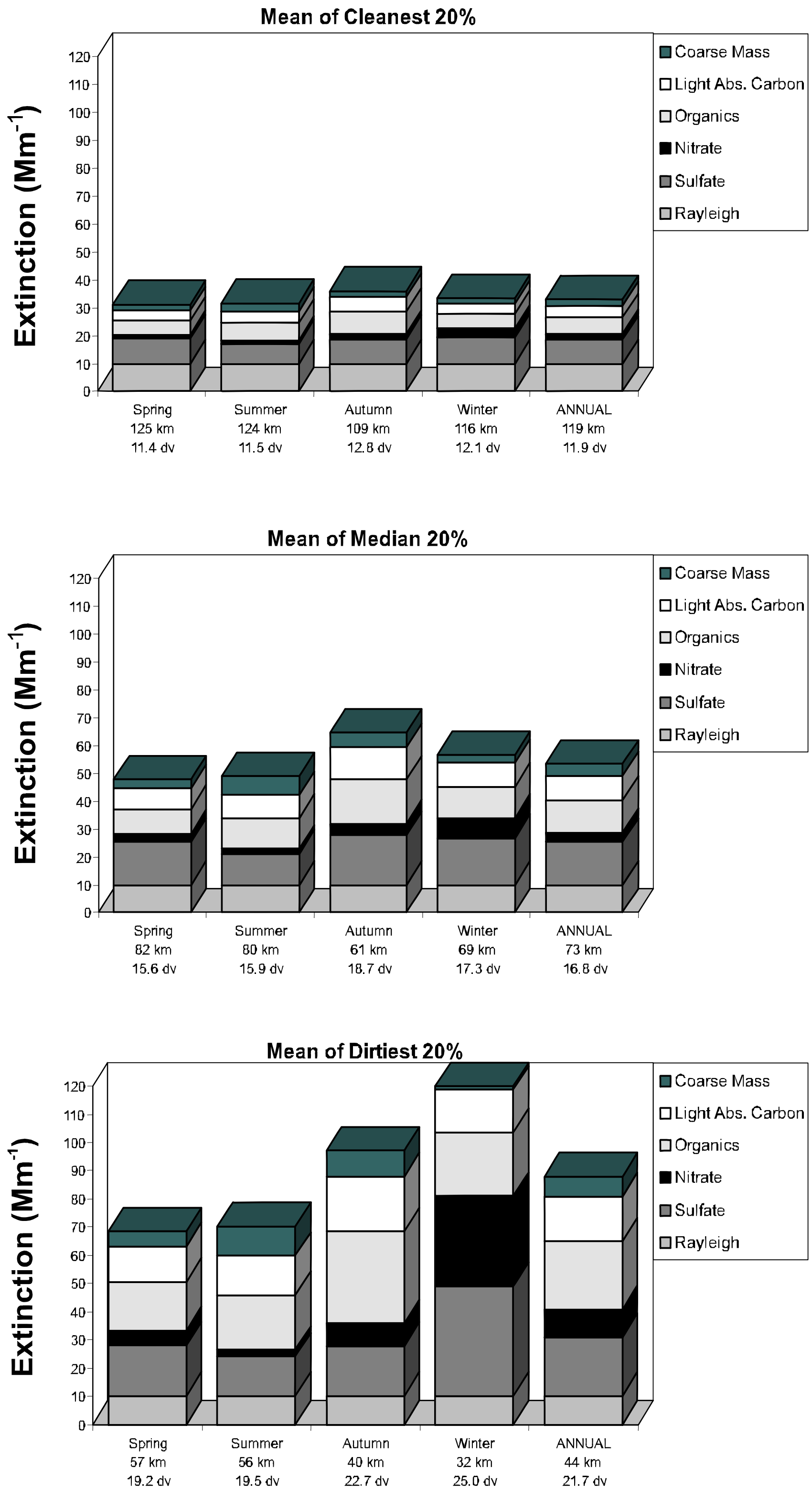


Figure IX-2. Reconstructed extinction budgets for BADL, March 1988 - February 1995.

used to run plume and regional haze models ant to analyze trends and conditions. Because of the larger spatial and temporal range of the aerosol data, reconstructed extinction data are preferred.

b. Transmissometer Data - Optical Monitoring

The transmissometer system consists of two individually-housed primary components: a transmitter (light source) and a receiver (detector). The light extinction coefficient (b_{ext}) at any time can be calculated based on the intensity of light emitted from the source and the amount of light measured by the receiver (along with the path length between the two). Transmissometers provide continuous, hourly b_{ext} measurements. Meteorological or optical interference factors (such as clouds, rain, or a dirty optical surface) can affect transmissometer measurements. Collected data that may be affected by such interferences are flagged invalid, “filtered.” Seasonal and annual data summaries are typically presented both with and without weather-influenced data. Detailed descriptions of the transmissometer system and data reduction and validation procedures used can be found in Standard Operating Procedures and Technical Instructions for Optec LPV-2 Transmissometer Systems (ARS, 1993 and 1994).

Table IX-6 provides a tabular summary of the “filtered” seasonal and combined period arithmetic mean extinction values for the March 1988 through February 1995 period. Table IX-7 provides a tabular summary of the "filtered" seasonal and combined period 10% (clean) cumulative frequency values. Data are represented according to the following conditions:

- No data are reported for seasons when the percentage of valid hourly averages (including weather) compared to total possible hourly averages, was less than 50%.

- Annual data represent the mean of all valid seasonal b_{ext} values for each March through February annual period. No data are reported for years that had one or more invalid seasons.

- Combined season data represent the mean of all valid seasonal b_{ext} values for each season (spring, summer, autumn, winter) of the March 1988 through February 1995 period.

- Combined annual period data represent the unweighted mean of all combined seasonal b_{ext} values.

Figure IX-3 provides a graphic representation of the "filtered" annual mean, median, and cumulative frequency values (5th, 10th, 25th, 75th, 90th, and 95th percentiles). No data are reported for annual periods with one or more invalid seasons.

When comparing reconstructed (aerosol) extinction, Table IX-5 with measured (transmissometer) extinction, Table IX-6, the following differences/similarities should be considered:

- Data Collection - Reconstructed extinction measurements represent 24-hour samples collected twice per week. Transmissometer extinction estimates represent continuous measurements summarized as hourly means, 24 hours per day, seven days per week.

Table IX-6. Seasonal and annual arithmetic means transmissometer data (filtered) for BADL, March 1988 through February 1995.

Year	Spring (Mar, Apr, May)			Summer (Jun, Jul, Aug)			Autumn (Sep, Oct, Nov)			Winter (Dec., Jan. Feb.)			Annual (Mar – Feb)[a]		
	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv
1989	92	43	14.6	–	–	–	129	31	11.3	114	35	12.5	***	***	***
1990	90	44	14.8	92	43	14.6	111	36	12.8	121	33	11.9	102	39	13.6
1991	105	38	13.4	78	51	16.3	108	37	13.1	125	32	11.6	101	40	13.7
1992	92	43	14.6	73	54	16.9	92	43	14.6	111	36	12.8	90	44	14.8
1993	105	38	13.4	129	31	11.3	129	31	11.3	125	32	11.6	121	33	11.9
1994	84	47	15.5	65	61	18.1	95	42	14.4	143	28	10.3	89	45	14.9
Mean[b]	94	42	14.4	83	48	15.7	109	37	13.0	122	33	11.8	120	33[c]	12.0

--No data are reported for seasons with <50% valid data.

*** No annual data are reported for periods with one or more invalid seasons.

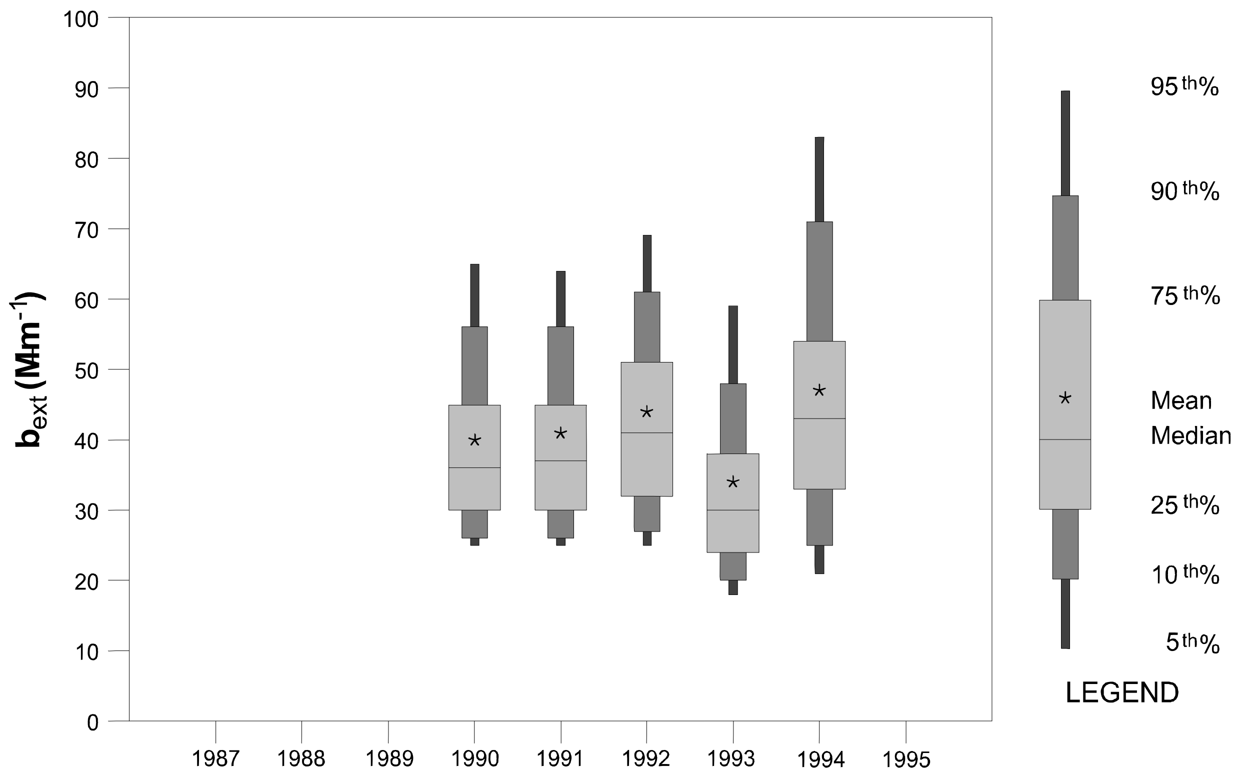
[a] Annual period data represent the mean of all valid seasonal b_{ext} means for each March through February annual period.

[b] Combined season data represent the mean of all valid seasonal b_{ext} means for each season of the March 1988 through February 1995 period.

[c] Combined annual period data represent the mean of all combined seasonal b_{ext} means.

Table IX-7 Seasonal and annual 10% (clean) cumulative frequency statistics transmissometer data (filtered) for BADL, March 1988 through February 1995.

Year	Spring (Mar, Apr, May)			Summer (Jun, Jul, Aug)			Autumn (Sep, Oct, Nov)			Winter (Dec., Jan. Feb.)			Annual (Mar – Feb)[a]		
	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv	SVR (km)	b_{ext} (Mm^{-1})	dv
1988	–	–	–	–	–	–	255	16	4.7	239	17	5.3	***	***	***
1989	192	21	7.4				202	20	6.9	191	25	9.2	***	***	***
1990	143	28	10.3	143	28	10.3	154	26	9.6	161	25	9.2	150	27	9.8
1991	148	27	9.9	105	38	13.4	161	25	9.2	154	26	9.6	138	29	10.6
1992	133	30	11.0	97	41	14.1	143	28	10.3	192	22	7.9	132	30	11.1
1993	175	23	8.3	225	18	5.9	183	22	7.9	239	17	5.3	202	20	6.9
1994	125	32	11.6	97	41	14.1	154	26	9.6	225	18	5.9	132	29	10.7
Mean[b]	149	27	9.9	120	33	12.0	173	23	8.5	188	21	7.6	210	19[c]	6.6



Note: For a specific year to be plotted, at least 50% of the data for each season must be valid.

-- No data are reported for seasons with <50% valid data.
***No annual data are reported for periods with one or more invalid seasons.
[a] Annual data represent the mean of all valid seasonal b_{ext} values for each March through February annual period.
[b] Combined season data represent the mean of all valid seasonal b_{ext} values for each season of the March 1988 through February 1995 period.
[c] Combined annual period data represent the mean of all combined seasonal b_{ext} values.

Figure IX-3. Annual arithmetic mean and cumulative frequency statistics, BADL, South Dakota, transmissometer data (filtered).

- Point versus Path Measurements - Reconstructed extinction represents an indirect measure of extinction at one point source. The transmissometer directly measures the irradiance of light (which calculated gives a direct measure of extinction) over a finite atmospheric path.

- Relative Humidity (RH) Cutoff - Daily average reconstructed measurements are flagged as invalid when the daily average RH is greater than 98%. Hourly average transmissometer measurements are flagged invalid when the hourly average RH is greater than 90%. These flagging differences often result in data sets that do not reflect the same period of time, or misinterpret short-term meteorological conditions.

  Note: The weather algorithm only flags 10%-20% of the data for a majority of the sites west of the Mississippi River. RH cutoffs have little effect on final mean extinctions in the western United States.

Reconstructed extinction is typically 70%-80% of the measured extinction. With a ratio of 72%, this relationship shows good agreement for BADL.

c. <u>Camera Data - View Monitoring</u>

Color 35mm slide photographs of Sheep Mountain were taken three times per day. View monitoring slides document visual conditions and are an effective tool for interpreting the visual effects of measured optical and aerosol parameters or presenting monitoring program goals, objectives, and results to decision-makers and the public. The Sheep Mountain photographs presented in Figure IX-4 were chosen to provide a feel for the range of visibility conditions possible and to help relate the extinction/SVR/haziness data to the visual sense.

d. <u>Visibility Summary</u>

Data from other IMPROVE visibility sites around the country have been presented graphically (Figures I-1 and I-2) so that visual air quality in the Rocky Mountains and northern Great Plains regions can be understood in perspective. Figure IX-6 and Table IX-6 have been provided to summarize BADL visual air quality during the March 1988 through February 1995 period. Seasonal variance in the mean of the dirtiest 20% fractions are driven primarily by sulfate and nitrate extinctions. Long-term trends fall into three categories: increases, decreases, and variable. Given the visibility sites summarized for this report, the majority of data show little change or trends.

Non-Rayleigh atmospheric light extinction at BADL is largely due to sulfate, organics, nitrates, and soil. Historically, visibility varies with patterns in weather, winds (and the effects of winds on coarse particles) and smoke from fires. No information is available on how the distribution of visibility conditions at present differs from the profile under "natural" conditions, but the cleanest 20% of the days probably approach natural conditions (Grand Canyon Visibility Transport Commission 1996). Smoke from frequent fires is suspected to have reduced pre-settlement visibility below current levels during some summer months.

D. AIR QUALITY RELATED VALUES

1. Surface Waters

Surface waters at BADL are mostly ephemeral in nature, and most of the small pools of water remaining after rainfall contain a large amount of clay in colloidal suspension. These small pools are bioindicators for the potential impacts of acidic deposition. Acid neutralizing capacity (ANC) is the best indicator of buffer capacity against acidic input. Although there are no data on ANC for the pools at BADL, the high clay content suggests that ANC would be very high, with no reasonable possibility of current levels of deposition reducing ANC measurably or of affecting aquatic life in the pools.

Badlands National Park
on a "clear" day

Representative Conditions:
Visual Range: 320-380 km
b_{ext}: 12-10 Mm^{-1}
Haziness: 2-0 dv

Badlands National Park
on an "average" day

Representative Conditions:
Visual Range: 100-130 km
b_{ext}: 39-30 Mm^{-1}
Haziness: 14-11 dv

Badlands National Park
on a "dirty" day

Representative Conditions:
Visual Range: 60-80 km
b_{ext}: 65-49 Mm^{-1}

Haziness: 19-16 dv

Figure IX-4. Photographs illustrating visibility conditions at Badlands National Park.

Figure IX-4. Photographs illustrating visibility conditions at Badlands National Park.

2. Vegetation

Vegetation is the resource which is most sensitive to ozone and SO_2, and several tree species have been identified as potential biodindicators (see below). Additional studies are needed to evaluate the impact of SO_2 and ozone on terrestrial ecosystems in BADL. While ozone and SO_2 levels at BADL have not exceeded the NAAQS, it is possible that there may be subtle effects under current conditions; increased concentrations in the future could potentially damage sensitive plant species. Furthermore, baseline data on the condition of sensitive species in the absence of injurious pollutants will be helpful for comparison with future conditions if pollutant levels increase. Monitoring bioindicators by using detailed descriptions and classifications of leaf or plant injury assists in the long-term evaluation of ecosystem health.

Bioindicators exist for which pollutant sensitivity has been documented and for which extensive data exist on their dose-response relationship to pollutants and on symptomatology. In some cases, these species can be important indicators of exposure of a pollutant at a site where air quality monitoring data are not available. Ozone and SO_2 are the most extensively studied pollutants regarding impacts on vegetation. Much of this work has been conducted on species native to the northeastern and southwestern United States and very little work on air pollutant effects has been conducted on species of the Rocky Mountains and northern Great Plains.

Although ponderosa pine is not common in BADL, it is present in the Sheep Mountain area on approximately 80 ha. Ponderosa pine is one of the most ozone-sensitive western tree species (especially var. *ponderosa*) for which extensive data are available on field (Miller and Millecan 1971, Pronos and Vogler 1981, Peterson and Arbaugh 1988) and experimental (Temple et al. 1992) exposures. The evidence for ozone impacts on ponderosa pine is based on observable symptoms of foliar chlorosis and reduced growth (Peterson et al. 1991, Peterson and Arbaugh 1992) as well as physiological (Darrall 1989, Bytnerowicz and Grulke 1992) data. The cause-and-effect relationship, especially for trees growing in forests of southern California and the southern Sierra Nevada, is clear and quantifiable. The Rocky Mountain variety of ponderosa pine (var. *scopulorum*) is known to be somewhat more tolerant to ozone and has a higher threshold for symptoms of injury under experimental exposures than var. *ponderosa* (Aitken et al. 1984).

Of the hardwood species present at BADL, green ash is the most sensitive to ozone. Green ash grows in riparian areas of BADL and is more common in the North Unit. Diagnostic ozone symptomatology for green ash includes dark pigmented stippling and bifacial interveinal necrosis (NAPAP, undated). Green ash does not have the clarity of ozone symptomatology found in ponderosa pine but can be used as a secondary bioindicator.

Green ash is also sensitive to SO_2 and may be the best bioindicator for this gaseous pollutant since SO_2 injury in conifer species is difficult to diagnose. There may be species present at BADL that are more sensitive to SO_2, but until such time as there is sufficient information on their dose-response relationship and symptomatology, green ash should be used as a bioindicator. Species with determinate terminal growth, such as green ash, are more sensitive to SO_2 early in the summer. There could be some confusion of ozone injury and SO_2 injury.

An inventory of vascular plants found in BADL was compiled in 1988 and is available in the NPFlora database. Table IX-8 summarizes vascular plant species of BADL with known sensitivity to ozone, SO_2, and NO_x. This table is based on a variety of sources from the published literature and other information. It should be noted that the various sources used a wide range of field and experimental approaches to determine pollutant pathology, and that sensitivity ratings are general estimates based on published information and our expert opinion. While park staff will not be able to collect data on all the species indicated in Table IX-8, the list can be used by park managers to indicate potentially sensitive species. Of the many plant species in BADL, it is likely that there are many other species which have high sensitivity to air pollution, but we currently have no information about them.

Table IX-8. Plant species of BADL with known sensitivities to SO_2, ozone, and NO_x. L = low, M = medium, H = high, none = unknown. (Sources: Esserlieu and Olson 1986, Bunin 1990, Peterson et al. 1993, National Park Service 1994, Electric Power Research Institute 1995, Binkley et al. 1996)

Species Name	SO_2 Sensitivity	O_3 Sensitivity	NO_x Sensitivity
Acer negundo	M	M	
Achillea millefolium		L	
Agoseris glauca	M		
Agropyron smithii	M		
Amaranthus retroflexus	M		
Ambrosia psilostachya		L	
Artemisia ludoviciana	M		
Atriplex canescens	L		
Atriplex confertifolia	L		
Bouteloua gracilis	L		
Bromus tectorum		M	
Chrysothamnus nauseosus	M		
Cirsium arvense		L	
Clematis ligusticifolia	M		
Collomia linearis		L	
Convolvulus arvensis	H		
Crataegus succulenta	L		
Descurainia pinnata		L	
Festuca octoflora		L	
Fraxinus pennsylvanica	M	H	
Gutierrezia sarothrae	M		
Hackelia floribunda	L		
Helianthus anuus	H	L	
Juniperus scopulorum	L		
Medicago sativa		M	
Oryzopsis hymenoides	M		

Table IX-8. Continued.			
Species Name	SO_2 Sensitivity	O_3 Sensitivity	NO_x Sensitivity
Phlox hoodii	L		
Pinus ponderosa	M	H	H
Poa pratensis	M	M	
Populus deltoides	M	L	
Potentilla fruticosa		L	
Prunus virginiana	M	H	
Rhus trilobata	L		
Ribes americanus	M		
Rosa woodsii	M	L	
Spartina pectinata	M		
Symphoricarpos albus		H	
Taraxacum officinale		L	
Toxicodendron radicans	L	L	
Tragopogon dubius	M		
Trifolium pratense	L		
Ulmus americana	M		
Vicia americana		L	
Yucca glauca	L		

Table IX-9 summarizes lichen species of BADL with known sensitivity to ozone and SO_2. As in Table IX-8, this table is based on a variety of sources from the published literature and other information. It should be noted that diagnostic symptoms of air pollutant injury to lichens are difficult to identify, and that some species have reduced productivity or even mortality without exhibiting visible symptoms (Nash and Wirth 1988). One of the best sources of background information and guidelines for addressing the use of lichens as bioindicators of air pollution is Stolte et al. (1993).

Table IX-9. Lichen species of BADL with known sensitivities to SO_2 and ozone. L = low, M = medium, H = high, none = unknown. (Sources: Peterson et al. 1993, Electric Power Research Institute 1995, Binkley et al. 1996, Will-Wolf 1997)

Species	Ozone sensitivity	SO_2 sensitivity
Acarospora chlorophana		H
Buellia punctata		L-M
Caloplaca cerina		M-H
Caloplaca flavorubescens		H
Caloplaca holocarpa		M
Candelaria concolor		M-H
Candelariella vitellina		M
Cladonia chlorophaea		M
Cladonia fimbriata		M
Collema tenax		M
Hyperphyscia adglutinata		M
Lecanora chlarotera		M

Table IX-9. Continued		
Species	Ozone sensitivity	SO_2 sensitivity
Lecanora dispersa		L
Lecanora hageni		L
Lecanora muralis		M
Melanelia exasperatula		M
Melanelia subaurifera	H	
Ochrolechia androgyna		H
Parmelia sulcata	M-H	L-H
Peltigera canina	H	L
Peltigera didactyla	H	
Phaeophyscia ciliata	M	
Phaeophyscia nigricans		L-M
Phaeophyscia orbicularis		M
Physcia adscendens		M
Physcia aipolia		M
Physcia millegrana		M
Usnea hirta		M-H
Xanthoria elegans		M
Xanthoria fallax		M-H
Xanthoria polycarpa	L	M

E. RESEARCH AND MONITORING NEEDS

1. Deposition and Gaseous Monitoring

The NADP data available from the Cottonwood site 20 km from BADL should be adequate to characterize wet deposition at BADL. If park managers want better quantification of deposition at BADL, short-term collection of wet deposition data could be used to calibrate with the Cottonwood site and establish a reference for deposition of S and N. Short-term collection of dry deposition data using NDDN-type collectors would further establish this reference for deposition, but is probably not warranted at the present time. If additional sources of pollutants (e.g., large sources such as power plants, small sources such as oil wells), are developed in the vicinity of the park, long-term deposition data for the park would help identify potential trends in emissions associated with those sources.

A better spatial characterization of ozone distribution at BADL would be useful, although levels are currently below those believed to adversely affect sensitive plant species. A network of passive ozone samplers could be established to compare ozone measurements from different locations in the park. Three samplers in the North Unit and three in the South Unit should be sufficient to spatially characterize the ozone distribution, with weekly samples for two months during the summer. Another sampler in the North Unit could be situated in the Badlands Wilderness with the third located equidistant between the first two. Samplers in the South Unit could be situated in (1) Palmer Creek Unit, (2) western Stronghold Unit, and (3) eastern Stronghold Unit. Samplers should be situated where they are reasonably accessible but not within 50 m of a road or trail where they may be subject to excessive dust or vandalism. Two years of monitoring should be sufficient to establish spatial patterns and a reference point in time.

Operation of an SO_2 analyzer at the Park Headquarters would provide a better characterization of SO_2 deposition at BADL. Two years of monitoring should be sufficient to establish a reference point for SO_2. Because the state of South Dakota does not have an active SO_2 monitoring program, BADL should document any future changes in air quality.

2. Terrestrial Systems

Although the park has passed its fiftieth anniversary and is the primary representative of the prairie biogeographic region in the National Park System, a basic inventory of many natural resources is still in its infancy (BADL 1994). Monitoring schemes, short and long term, are similarly lacking, making it impossible to compare data over time to predict or assess changes. If the concentrations of ozone, SO_2, or NO_2 increase in the future, it will be important to document the condition of terrestrial resources of BADL so that a reference point in time is established.

If pollutant levels increase in the future, monitoring of terrestrial resources should be considered. If monitoring is implemented, we recommend that ponderosa pine and green ash be used as bioindicators for ozone and green ash for SO_2 at BADL. One plot of each species should be sufficient for initial monitoring. Three levels of monitoring associated with increasing amounts of effort and expense are detailed in Appendix A. Co-location of these plots with the passive ozone samplers should be done wherever possible. Monitoring should follow the methodology developed by U.S. Forest Service and National Park Service scientists for evaluating pollutant injury (Stolte and Miller 1991, Stolte et al. 1992).

If herbaceous species and lichens are included in a future monitoring effort, plots should be established adjacent to the tree plots if possible. Monitoring methodologies can be found in Appendix A. Inventories of lichen species distribution and abundance in BADL would provide a better baseline for further assessment of potential impacts of air pollution on lichens in the Park.

3. Visibility

IMPROVE aerosol and optical monitoring should continue at BADL. Ongoing and future monitoring is necessary to identify local source impacts. Additional data and in-depth modeling and analysis are required to further evaluate historical trends and projections of impact from existing and future sources. For example, back trajectory analysis and spatial/temporal pattern analysis of episodes are recommended to determine the source region contributions to elevated aerosol concentrations. Future research is also recommended to minimize the uncertainty in estimates of how various aerosol species affect visibility.